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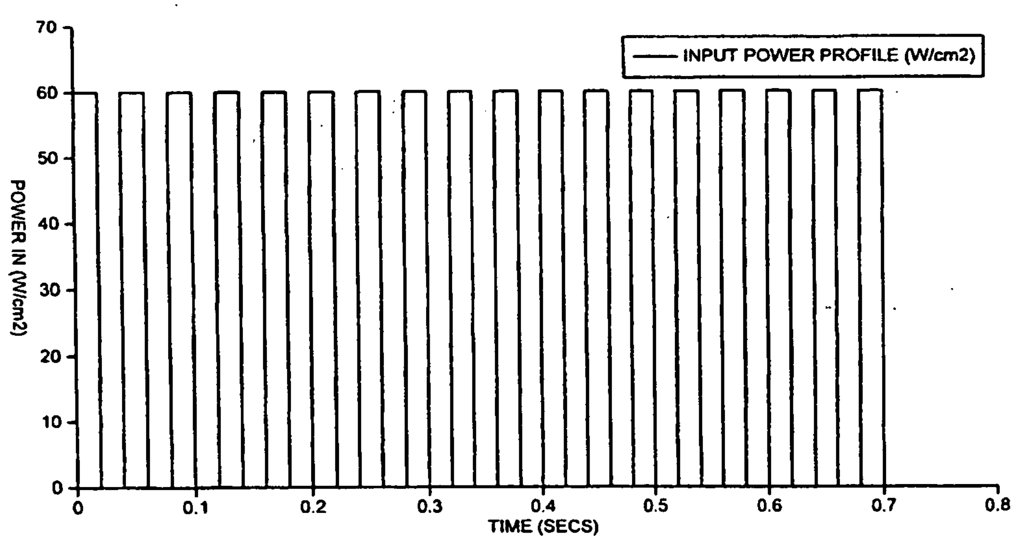

(57) Abstract: A method of reducing the power output of a thick film heater to a predetermined fraction of its maximum power is disclosed. The method comprises applying a series of regular periodic bursts of electrical energy to the heater wherein the bursts are sufficiently short that the face of the heater plate opposite the heating track does not reach an equilibrium temperature. Also disclosed is a method of detecting dry switch-on by applying a lower power at the start of heating and determining whether a threshold rate of temperature rise is exceeded. In a method of calibrating a temperature sensor, the resistance at boiling and at another temperature (the latter e.g. being measured during manufacture) are measured and interpolation or extrapolation used. Other methods for estimating volume, reducing power as a given temperature is approached and detecting scale build-up are also disclosed.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Electric Heaters

This invention relates to electric heaters, particularly those for heating liquids, and to various methods of controlling such heaters.

In the field of water heating vessels it is rapidly becoming more and more common to use a thick film printed element heater mounted to close an opening in the base of the vessel. Such heaters comprise an electrically resistive track printed onto an insulating layer on a metallic substrate. One of the advantages of thick film heaters is their ability to deliver high watts densities and high overall powers.

However another important advantage which is emerging is the flexibility which is afforded to the designer of the heater by being able to provide any number of separate heating tracks which may have different powers and which may be used separately or in combination with one another. Thus for example whilst kettles and jugs sold in Europe are almost always designed simply to boil water, liquid heating vessels designed for the Far East are usually also designed to simmer water for a prolonged period. The designer of such an appliance can therefore provide a main high power heating track for heating water to boiling and a second low-power track for keeping the water simmering thereafter. An example of such an arrangement is disclosed in WO97/04694.

It is also known in the Millennium M2 jug to maintain the water at a temperature below boiling. This is achieved thermostatically, i.e. the heater is energised for a short time whenever the water temperature is determined to have fallen below a threshold value. Given the relatively low rate at which heat diffuses through the water resulting from its high

thermal capacity of water and low rates of convection, this heating regime gives a relatively constant average temperature throughout the water despite the discontinuous application of power.

However the Applicants have realised that whilst the bulk temperature of the water remains relatively constant, the instantaneous temperature of the water where it meets the surface of the heater should also be taken into account. This temperature will rise rapidly to the normal value it reaches while heating the water to boiling, before falling off again when the heater is deenergised as heat diffuses through the body of water. Whilst this has the overall desired effect of maintaining the water at an approximately constant temperature, the water at the heater surface undergoes local boiling which generates undesirable noises.

Furthermore, it has been recognised that the characteristics described above have so far precluded this type of heater from being used to heat other liquids with an even lower rate of thermal diffusivity - i.e. having lower thermal conductivity and greater viscosity which inhibits convection, e.g. milk, which would be burnt by the excessive temperature at the heater surface even though the power averaged over a number cycles might be relatively low.

When viewed from a first aspect the present invention provides a method of reducing the power output of a thick film heater to a predetermined fraction of its maximum power, said heater having a planar substrate which is electrically insulating on at least one face thereof and an electrically resistive heating track applied to said insulating face, said method comprising applying a series of regular periodic bursts of electrical energy to said heater wherein the bursts are sufficiently short that the face of the heater plate opposite the heating track does not reach an equilibrium temperature.

From another aspect the invention provides a heating apparatus comprising a thick film heater having a planar substrate which is insulating on at least one side and an electrically resistive heating track applied to said insulating face, and an electronic control arranged to apply a series of regular periodic bursts of electrical energy to said heater wherein the bursts are sufficiently short that the face of the heater plate opposite the heating track does not reach an equilibrium temperature.

Thus it will be seen that in accordance with the invention very short bursts of energy are supplied to the heater so that the opposite surface, i.e. that in contact with whatever is being heated e.g. a liquid, does not have an opportunity to reach an equilibrium temperature, that is the temperature it would otherwise reach if power were to be applied continuously. The average power output of the heater will of course depend on the ratio of the duration of the bursts to the interval between them, i.e. the mark-space ratio, as is already known. However by restricting the absolute duration of the bursts in accordance with the invention, the maximum temperature experienced at the heating surface of the thick film heater can be significantly reduced. This means for example that liquid e.g. water can be heated at a reduced power without local boiling taking place (and therefore without any substantial noise being generated) where it would otherwise have taken place. It also opens up the possibility of heating other liquids with a given high watts density heater which would not be able to tolerate the watts density associated with the heater operating at full power, e.g. milk or soup. Indeed such a heater may be used to heat solids or semi-solids such as foodstuffs and the like.

It will be appreciated by the skilled person that effectively the present invention allows a high watts

density thick film heater to be converted to one with a lower watts density. This is advantageous over arrangements in which a separate low watts density track is provided for example since it continues to allow even heating across the heater, whilst minimising the size and therefore cost of the heater.

The maximum duration of energy burst which will prevent the far surface of the heater from reaching equilibrium will of course depend on the thickness and thermal conductivity of the insulating layer and metallic substrate, and on the power rating of the heating track. In preferred embodiments the duration of the burst is less than 500 mS, more preferably less than 200 mS, more preferably less than 100 mS. In some preferred embodiments a burst of just 20 mS is utilised.

Where, as will almost always be the case, the heater is supplied with an alternating current (A.C.) electricity source, the burst duration is preferably a whole number of cycles. This enables the beginning and end of the power burst to be set where the voltage crosses the zero line. This minimises electromagnetic interference since the load is switched under zero current conditions (the heater being almost a completely resistive load). Thus the preferred maximum burst durations given above presume operation on the UK's 50 Hz A.C. mains supply and correspond respectively to 25, 10, 5 and 1 cycle(s). These preferred burst durations should be revised accordingly when another frequency, e.g. 60 Hz is employed.

Any suitable means for switching the electrical power to the heater may be employed with a triac or the like being presently preferred.

The effective reduction in watts density of a thick film heater which is provided by the present invention is useful in many contexts. In particularly preferred embodiments such a heater is incorporated in a liquid heating apparatus. In one preferred embodiment the

reduction in power is used to operate the liquid heating apparatus so that it heats e.g. water, preferably to boiling, substantially without generating any discernible noise. Of course it will be understood that when a liquid is heated to boiling, the boiling will inevitably generate some noise. The substantial elimination of noise is therefore intended to refer to the stage prior to boiling throughout the liquid takes place.

It will be appreciated that such an arrangement is novel and inventive in its own right and thus when viewed from a further broad aspect the present invention provides a method of raising the temperature of a liquid in a liquid heating apparatus, said method comprising energising the heater at such a power that substantially no discernible noise is generated during heating.

The invention also extends to a liquid heating apparatus having an electric heater and a control which is arranged to operate the apparatus in this way, and to the control *per se*.

The apparatus may be arranged so as to operate permanently in this way. Preferably however a user is able to select this mode of operation when quiet heating is required, but can also select a higher power mode to expedite heating when noise is not of concern. The quiet mode may just be pre-selectable prior to the commencement of heating. Preferably however it can be selected during heating as well. Thus if a user begins to heat liquid in the apparatus at a high power but then e.g. is required to answer the telephone, he or she can select a quite mode until such time as the telephone conversation has ended or the desired water temperature is reached. It may also be preferred that selection of the quiet mode also suppresses sounds deliberately generated by the apparatus such as a notifying "ping" upon the completion of heating.

In some preferred embodiments, the power applied to

the heater in order to avoid noise generation is predetermined, e.g. empirically. A fixed power level may be used, but preferably a minimal noise heating programme is devised in which the power level is adjusted to minimise noise whilst maximising the power to minimise heating time. The Applicant has realised that the noise produced during normal heating of e.g. water varies. For example it has been realised that very little noise is generated when power is first applied as the apparatus warms up, the noise increases as the heat reaches the water, reduces again as convection within the water begins to take place and then gradually increases towards boiling. In accordance with a preferred method therefore a predetermined power profile is applied, the profile being determined so as to maximise the power at a given point thereof whilst minimising the generation of noise.

This is novel and inventive in its own right and thus from a further aspect the present invention comprises a method of heating liquid in an electric liquid heating vessel comprising applying power to the heater of the vessel in a predetermined profile, said profile being derived so as to maximise the power applied at any given time whilst minimising the generation of noise.

The invention also extends to an electric liquid heating apparatus comprising control means arranged to operate the apparatus in this way and to said control means *per se*.

Alternatively or additionally, the apparatus comprises means to detect the level of sound being generated and means to adjust the power applied to the heater according to the sound level detected in order substantially to avoid any discernible noise being generated. Thus if it is desired to operate the apparatus at a reduced noise level, the power may be reduced to an initial low value and then steadily

increased until noise above a certain threshold is generated. The power may then be reduced again slightly. If noise is determined again to be above the threshold the power can then be reduced further.

This arrangement is beneficial since it minimises the time taken to heat the liquid whilst maintaining operation at a reduced noise level. It also automatically accounts for changes in the propensity for noise to be generated during the heating process, especially as the liquid approaches whole scale boiling.

This method of reducing noise is also beneficial in its own right and thus when viewed from a further aspect the present invention provides a method of reducing the generation of noise whilst heating a liquid in an electric liquid heating apparatus comprising measuring the level of noise electronically and regulating the electrical power applied to the element according to the level of noise measured.

When viewed from a further aspect the invention also provides an electric liquid heating apparatus comprising electronic sound sensing means to sense the level of noise generated when the apparatus is heating a liquid and means to regulate the electrical power applied to the heater of the apparatus according to the level of noise detected.

Any electronic transducer capable of detecting sound may be used, e.g. a microphone. The sensor may be placed in the liquid receiving chamber of the apparatus but is preferably located on the "dry" side of the heater. This facilitates manufacture and helps to ensure reliability.

The sound sensing means may detect the overall level of sound, but preferably it is arranged to detect only a smaller range of frequencies. This helps to avoid unreliable functioning resulting from high ambient noise etc. Preferably therefore the sound sensing means senses substantially only frequencies below 500Hz, also

preferably above 50Hz.

Another particularly beneficial application of the previously disclosed method of reducing power is in the detection of dry switch-on in a liquid heating apparatus. More particularly in a preferred embodiment the present invention provides a method of operating a thick film electric heater for a liquid heating apparatus comprising applying a reduced power to the heater in accordance with the first aspect of the invention; determining whether the rate of temperature rise of the heater is above or below a predetermined threshold value and increasing the power applied if the rate of temperature rise is below the threshold rate, but interrupting the supply of power to the heater if the detected rate of temperature rise is above the threshold rate.

Thus it will be seen that in accordance with this preferred embodiment a lower power, e.g. half maximum power, is applied initially. If the apparatus has been filled normally the resultant rate of temperature rise will be relatively low and should be well below the threshold value to avoid nuisance tripping. However if the apparatus has been switched on without any liquid in it to dissipate the heat generated, the resultant temperature rise will be significantly faster. The threshold rate is set such that it is lower than the dry switch-on rate of temperature rise and so the apparatus will interrupt the supply of power.

Not only is this an effective way of detecting dry switch-on but it is also inherently safer since full power is never applied if the apparatus is switched on dry and so the temperatures reached by the heater, seal, vessel wall etc., before the power is cut will be significantly lower than if full power had been applied for the same length of time.

Such arrangements are novel and inventive in their own right, irrespective of the method used to reduce the

power and thus when viewed from a further aspect the present invention provides a method of operating a thick film heater for a liquid heating apparatus comprising applying a reduced power to the heater; determining whether the rate of temperature rise of the heater is above or below a predetermined threshold value and increasing the power applied if the rate of temperature rise is below the threshold rate, but interrupting the supply of power to the heater if the detected rate of temperature rise is above the threshold rate.

The invention also extends to a liquid heating apparatus having a thick film heater closing an opening in the base thereof and a control capable of operating the apparatus in this way; and to such a control *per se*.

The determination of whether the rate of temperature rise is above or below the threshold could be made by looking for a predetermined temperature being achieved within a corresponding threshold time or by looking for a threshold temperature after a predetermined time. Preferably however an actual value for the rate of temperature rise is measured. This value can then be compared directly to the threshold rate.

In one preferred embodiment the full power rating of the heater is 3kW but this is reduced to 1.5kW when it is first energised. The threshold being set at $8^{\circ}Cs^{-1}$, i.e. if the temperature of the heater rises more quickly than this it is assumed to have been switched on dry.

The rate of temperature rise could be measured over a predetermined period, e.g. one second. Alternatively the time taken for the temperature to rise by a predetermined amount could be measured. Although this may be slightly more complicated to implement, it is beneficial in that it effectively allows the maximum temperature reached by the plate during a dry switch-on to be limited to a predetermined value. The temperature

signifying the end of the rate of rise measurement could even be set to be the same or lower than the ordinary operating temperature of the heater. This would mean that the heater cannot overheat even if the apparatus is switched on dry.

In some preferred embodiments the comparison with the threshold rate could be made more than once with full power only being applied if the threshold is not exceeded on both or all occasions, but with power being interrupted if it is exceeded on any occasion. This is beneficial in guarding against the protection system being "fooled" by spots of liquid remaining on the heater from a previous use which might locally suppress the rate of temperature rise temporarily.

Once full power has been applied comparisons with the threshold rate of temperature rise need no longer be made. Preferably however comparisons are made continually whilst the liquid is being heated. This provides a further backup in the event that the low power measurement was incorrect for any reason, but more importantly it will give protection in the event that the apparatus is allowed to boil dry, e.g. if the apparatus is set to simmer for a long period of time.

In fact it has been recognised that applying a lower power initially may be beneficial in detecting dry switch on even if the measurement of rate of temperature rise is not made until full power is applied. This stems from the realisation that large transient effects often take place upon initial heating and therefore it the rate of temperature rise may fluctuate too much for it to be a useful indicator of dry switch-on in this phase. The benefits of minimising the temperatures reached during dry switch-on remain however.

Thus when viewed from a further aspect the present invention provides a method of operating an electric liquid heating vessel comprising applying a reduced power to the heater of the vessel for a predetermined

period, applying higher power thereafter and determining whether the rate of temperature rise of the heater is greater than a predetermined threshold value, and interrupting the power to the heater if the rate of temperature rise is above the threshold rate, but continuing to heat the liquid if it has below the threshold rate.

The invention also extends to a liquid heating apparatus comprising control means arranged to operate the apparatus in this way and to said control means *per se*.

The higher power in accordance with this aspect of the invention is preferably full power. This is advantageous since it means that the threshold rate of temperature rise for determining whether a dry switch-on has taken place can be set at a level suitable for full power and therefore the same value can be used to detect

In a preferred embodiment of this aspect of the invention the lower power, e.g. 1.5kW is applied for a predetermined period of time, e.g 3 seconds and power is then automatically interrupted for a further predetermined period, e.g. 2 seconds before full power, e.g. 3kW is applied. The apparatus is then arranged to determine whether the rate of temperature rise exceeds a threshold of $6^{\circ}Cs^{-1}$. Furthermore this threshold is monitored throughout the operation of the apparatus in order to determine if it is allowed to boil dry.

As mentioned above, an actual value for the rate of temperature rise is preferably measured. In order to protect the heater against overheating due to being switched on dry, this is simply compared with a threshold rate to determine if it is higher or lower. However it has been further recognised by the Applicants that the value of the rate of temperature rise can be used to give an indication of the volume of water which is being heated. More particularly the volume can be calculated by taking into account the power output and

the specific heat capacity of the liquid e.g. water. Corrections to account for the efficiency of the heater and heat loss from the liquid, which may be determined empirically, might also be used.

It will be appreciated that this concept is novel and inventive in its own right and thus from a yet further aspect the invention provides a method of estimating the volume of a liquid of known heat capacity being heated by an electric liquid heating apparatus, said method comprising applying power to the heater of said apparatus, measuring the increase in temperature of said liquid over a given time and calculating said volume on the basis of the time, heat capacity and amount of energy supplied to the heater during said time.

The invention also extends to a liquid heating apparatus comprising control means which is arranged to operate as set out above; and to said control means *per se*.

It will be seen that in accordance with this aspect of the invention the rate rise in temperature of the liquid is used to calculate the volume of liquid. This could use the same calculated rate as is used to detect dry-switch-on, but preferably a separate calculation is carried out - e.g over a longer period so as to return a more accurate figure. In one particular example the calculation for the purposes of determining dry switch-on is made using an average of temperature measurements made over 5 seconds (a rolling average updated every second) whereas the calculation for determining volume is made over 20 seconds (again updated every second).

The temperature measurements may be made directly, e.g. with a suitable sensor in contact with the liquid. Preferably however the temperature is measured indirectly via the heater. This is significantly more convenient since it allows the sensor to remain dry and facilitates making electrical connection to it. The

sensor can even be the same as is used for protecting the heater, e.g. from dry switch-on. In the case of a thick film heater, the temperature sensor could be printed into the heater substrate or be separate from it as convenient.

Preferably the apparatus is arranged to reduce the power applied to the heater if the detected volume is above a predetermined level, i.e. if the apparatus is overfilled. This has clear benefits in helping to avoid the hazards of hot water splashing etc., associated with overfilling. Preferably a warning signal is given to the user so that he/she knows to empty out some of the liquid if it has been overfilled.

However it has been appreciated that knowledge of the volume of liquid is also useful even if the apparatus has not been overfilled. In a preferred embodiment power to the heater is reduced as the liquid approaches boiling if the volume of liquid is within a predetermined range from the maximum. This means that if the apparatus is full or near to full it will boil more gently than if it is less filled. This means that boiling is approached more gently and so it helps to prevent dangerous ejection of boiling water through the spout when the apparatus is relatively full. Consequently the need to provide a safety head space to avoid splashing etc., is reduced. This is clearly beneficial since it means that for a given liquid capacity, the size of the apparatus can be reduced. This is not only economical from the point of view of material costs, but it enhances the appearance and therefore customer appeal of the apparatus.

The reduced power at the higher ordinary operating temperatures associated with boil also places a lower burden on the power regulating device which will usually be a solid state device such as a triac and limits the ambient temperatures experienced generally within the apparatus which has beneficial implications e.g. for the

rating of electronic components.

In fact this concept does not rely on the volume of liquid being detected in accordance with the previously described method - the volume could be detected by any suitable means such as a float, or by measuring its weight. Thus when viewed from a yet further aspect the present invention provides a method of operating an electric liquid heating apparatus comprising detecting whether the volume of liquid in the apparatus is above a predetermined threshold, applying a first power to the liquid during a first heating phase in which the liquid is heated to an intermediate temperature and applying a second lower power during a second heating phase in which the liquid is brought to boiling

The invention also extends to an electric liquid heating apparatus comprising control means arranged to operate the apparatus in this way and to said control means *per se*.

The reduction of power may be effected in any convenient way but is preferably effected in accordance with the first aspect of the invention. The second, lower, power could be fixed in value and applied whenever the threshold volume is exceeded. Alternatively a sliding reduction could be employed so that the amount by which the power is reduced is dependent upon, e.g. proportional to, the proximity of the volume to the specified maximum.

It has also been appreciated that from a knowledge of the volume of liquid in the apparatus and also by monitoring the power regime applied to the heater, the time which it will take to heat the liquid to a given temperature (e.g. boiling) can be estimated. Thus preferably the apparatus comprises means to estimate the time that will be taken to reach a preset temperature. This time is preferably displayed to the user, most preferably throughout the heating process, i.e. as a countdown timer.

The volume estimate which is used to estimate the required heating time may be carried out during a low-power start-up as is disclosed earlier. Equally however the rate of temperature rise may be determined during a normal start-up or, preferably, at a later stage of heating - which is advantageous in that it can avoid inaccuracies arising from initial transient effects. Indeed the volume could be determined by any suitable alternative method as mentioned above, e.g. weight detection etc. It will be seen therefore that the concept of estimating the time until a given temperature is reached is novel and inventive in its own right and thus when viewed from a yet further aspect the present invention provides a method of estimating the time required to heat liquid of known heat capacity received in a liquid heating apparatus to a predetermined temperature comprising estimating the volume of liquid in the apparatus, determining the amount of power to be applied to the heater of the apparatus and determining the time required on the basis of the heat capacity, volume and total energy to be applied.

The invention also extends to a liquid heating apparatus comprising control means arranged to operate the apparatus in this way; and to said control means *per se*.

The estimate of time required may be made just once, e.g. at the commencement of heating. Preferably however it is updated during heating. This is particularly beneficial when the user is able to modify the power regime during heating, e.g. to select the "quiet" mode disclosed earlier.

In accordance with the aspects of the invention set out above the time to reach a given temperature is calculated from an estimate of the volume of liquid in the apparatus, which in some preferred embodiments is calculated from the rate of temperature rise. However

it has been appreciated that by extrapolating the rate of temperature rise an estimate of the time that will be taken to reach a given temperature can be estimated directly. Thus from a further broad aspect the present invention provides a method of estimating the time until a liquid received inside a liquid heating apparatus reaches a predetermined temperature comprising heating the liquid; measuring the rate of temperature rise and extrapolating said rate to said predetermined temperature.

The invention also extends to a liquid heating apparatus comprising control means arranged to operate the apparatus in this way; and to said control means *per se*.

Again just a single e.g. initial estimate could be made but preferably a revised estimate is made at least whenever the power applied to the heater of the apparatus changes. The estimated time is preferably displayed to the user, most preferably in the form of a countdown timer.

Whichever method is used to estimate of time to reach a given temperature, according to another invention disclosed herein the time estimate is used to set a fixed time for which power will be applied to the heater. More particularly this invention comprises a method of operating an electric liquid heating apparatus to heat liquid received therein to a predetermined temperature comprising estimating the time which will be taken to heat the liquid to said temperature; defining a fixed heating time based on said estimate of time and applying power for said fixed heating time and thereafter interrupting or reducing the power to the heater.

Although this concept appears comparatively simple it is contrary to all previous teaching in the art which is that if the heater in a liquid heating vessel is to be shut off automatically, this should be achieved

passively i.e. by measuring/sensing what is happening to the liquid through the temperature thereof or the generation of steam. This passive monitoring is then used to detect when the desired temperature, e.g. boiling, has been reached. However it is now proposed to monitor certain parameters of the liquid at an earlier phase of heating, use these to predict when the temperature will be reached and then actually fix the heating time on the basis of this prediction. This is advantageous since it means that temperature sensors giving accurate results at elevated temperatures are not required, i.e. the required dynamic range for the temperature sensor is reduced. This can reduce costs under some circumstances - e.g. by making calibration easier.

This concept may be used whatever the temperature to which the liquid is being heated, but is most applicable when the liquid is being heated to boiling. The reason for this is firstly that the requirement to measure temperatures around boiling gives rise to the maximum necessary dynamic range for the sensor. More importantly though, boiling is generally relatively difficult/costly to detect accurately either by measuring the liquid temperature or by detecting steam. In accordance with the invention proposed above however the need to detect boiling is completely obviated.

Furthermore the Applicants have appreciated that an additional benefit of this invention is that the estimated time to boil can be deliberately extended. Not only does this ensure that boiling actually takes place given the inevitable measuring inaccuracies, but also it enables boiling to be continued for a predetermined length of time. This may be just a few seconds in order to give the effect of a few seconds of rolling boil which is perceived to be desirable by consumers, especially those in the UK, or it may be for a longer period of time, e.g. to sterilise water. At

least in the latter case, the extended simmer time is preferably pre-settable and is preferably at a reduced power, preferably between 5% and 15% of full power.

This application also discloses a further invention.

This invention relates to controls for electric liquid heating apparatus and in particular to methods and apparatus for measuring the temperature of a liquid being heated.

With the advent of thick film heaters and an increasing preference amongst consumers for extended functionality on all household appliances, the interest in electronic controls for liquid heating vessels has re-emerged to some extent after previously being disregarded due to cost considerations.

One of the problems with electronic controls has been providing a reasonably accurate electronic sensor which is cost effective. It has been proposed in the prior art to use a sensor in the form of an additional printed track having a positive temperature coefficient of resistance in order to sense the temperature of the heater plate, either indirectly to sense the liquid temperature or to protect against overheating of the heater itself. Unfortunately it has been found in practice that large variations in the resistances of these sensor tracks occur as a result of variability in the inks used and in the printing process itself. In order to overcome this would have required uneconomical manual calibration of each heater.

Discrete thermistors are available with a sufficiently tight tolerance to overcome this problem, but these are relatively expensive. Conversely less costly components tend to require calibration in the way that printed tracks do.

It is the aim therefore to provide an arrangement which at least partly alleviates the above-mentioned disadvantages.

From a further aspect the present invention provides a method of calibrating a thermal sensor arranged to measure the temperature of the substrate of a thick film heater for a liquid heating apparatus, said method comprising noting the resistance of the sensor at a first temperature, heating liquid in the apparatus to boiling, noting the resistance of said sensor and thereafter using said two resistances to calculate by interpolation or extrapolation the temperature of the sensor at temperatures below boiling.

Thus it will be seen that in accordance with this aspect of the invention the resistance of the sensor is measured at two separate temperatures and the results used to calibrate the sensor to give temperature measurements at other temperatures. The first temperature could be above the second (the temperature measured when liquid in the vessel boils), for example the first resistance measurement could be made as the thick film heater is cooling after it has been fired, e.g. after having an overglaze applied. This is particularly applicable where the sensor is actually printed onto the heater substrate.

More preferably the first temperature is below the second and most preferably is approximately room temperature. This means that the two reference resistances are measured approximately at either end of the working range of the sensor.

The first temperature must of course be measured independently in order to calibrate the sensor. Thus this may conveniently be carried out during manufacture. A thermocouple or the like could for example be used.

The second temperature is measured when liquid in the vessel is at boiling temperature. This temperature could also be measured by independent means, but preferably it is inferred from the fact that liquid in the vessel is actually boiling. There are a number of ways in which this may be done. For example that

emission of steam could be detected or a visual check for boiling could be carried out by an operator. More preferably the sensor itself is used to detect boiling, not by the actual temperature, but by the rate of change of temperature, i.e. it is assumed that whatever the exact calibration of the sensor, its rate of change of resistance with time will tend to zero as liquid in the vessel boils. This has been found to be borne out in practice. In a particularly preferred embodiment, rather than measuring the rate of change of temperature itself, boiling is determined by extrapolating the tangent to the temperature profile back to say the start time of the heating process to calculate the corresponding intercept on the temperature axis. In other words the equivalent start temperature which would have given rise to the present temperature if the rate of temperature rise had been constant, is monitored. This value will start at the actual initial temperature of the heater and rise to the final boiling temperature. A threshold value of e.g. 80°C is defined to be when the boiling occurs.

Additionally or alternatively boiling may be inferred simply by calculating the energy input to the liquid required assuming that the vessel is filled to its maximum capacity and then energising the heater for a sufficient time to ensure that at least this amount of energy has gone into heating the liquid.

The Applicant has realised that as a consequence of the foregoing the second calibration step can be carried out by a suitably configured liquid heating apparatus itself. This opens up the possibility of the second calibration step being carried out away from the factory, e.g. by the consumer, albeit without realising. This is advantageous since it minimises the production and calibration time in the factory, thereby saving costs. Furthermore it alleviates any problems which would otherwise have been caused in the event that a

particular control which has been calibrated with a sensor on a particular heater become separated and mismatched since fine calibration can be performed after final assembly of a liquid heating apparatus has taken place. Such problems are most likely to arise where the control means are arranged in a cordless base of the apparatus whilst the sensor is arranged in a separate vessel part.

This feature is thus novel and inventive in its own right and from a second aspect the invention provides a liquid heating apparatus comprising electronic control means including a temperature sensor which has been partially calibrated, said control means being arranged to heat liquid in the vessel to boiling, to measure the resistance of said sensor when the liquid is boiling and to calibrate the sensor on the basis of said measured resistance.

In preferred embodiments the control means of the apparatus is arranged to carry out this calibration step the first time it is used by a consumer. Thus if boiling is to be inferred from the amount of energy put in, the consumer might be instructed to fill the apparatus to its maximum capacity the first time it is used. Of course the amount of energy required to boil the full capacity will also boil a lesser amount.

If the user prevents boiling from taking place on a first or subsequent use - e.g. by switching off the apparatus or removing it from its base in the case of a cordless appliance, the apparatus preferably retries to execute the calibration step on its next operation.

In accordance with the preferred method and by use of the apparatus of the invention, a second calibration step is effectively carried out by a user. Thus the user must operate the apparatus at least once with a sensor which is not fully calibrated. However the sensor will usually have a nominal pre-specified temperature dependence which can be used to extrapolate

its temperature dependence from the measurement made at the first temperature. Whilst this is likely to be inaccurate to some extent, it will be sufficiently accurate to ensure that the apparatus is not unsafe, i.e. the sensor in the preferred embodiment is able to distinguish between normal operation and dry switch-on/boil dry throughout its tolerance range.

Temperatures below boiling are preferably measured by interpolation of the resistances measured at the first temperature and boiling respectively. The Applicant has realised that the boiling temperature will not necessarily exactly match its theoretical value e.g. 100°C in the case of water. For example the altitude at which the boiling takes place will affect its temperature. Therefore the intermediate temperatures indicated may vary from their actual physical values. However since these intermediate temperatures are likely to be selected by a user in accordance with his/her personal preference, the absolute temperature is not of particular consequence. More importantly at a given altitude a selected temperature will be reasonably repeatable.

The form of the temperature dependence, and thus the nature of the constants which are derived from the resistance at the two calibration temperatures will depend upon the type of temperature sensor employed. For example if a positive temperature coefficient (PTC) thermistor is used, the temperature dependence will generally be, to a good approximation, a linear one - i.e. of the form:

$$R=R_0 + AT$$

where A is the temperature coefficient of resistance. In this case, the calibration temperatures are therefore used to establish values for R_0 and A.

In the preferred case of a negative temperature coefficient thermistor, the dependence is generally an exponential one, i.e. of the form:

$$R=R_0 - e^{-(BT)}$$

where B is a constant related to the so-called beta value of the thermistor (the exact relationship depending upon at what temperature R_0 is measured).

It has been found that whilst practical thermistors which are available require calibration to determine the constants set out above, the form of their temperature dependence - i.e. linear or exponential respectively, remains sufficiently accurate.

As mentioned previously, a thermal sensor in the form of a printed track of a suitably temperature sensitive ink may be used. It is presently preferred, however, to use a discrete thermistor in good thermal contact with the heater, most preferably one having a negative temperature coefficient of resistance since these tend to have a greater magnitude change in resistance with temperature, thus giving more precise results.

The boiling calibration step may be carried out just once, e.g. on its first use. In preferred embodiments however the steps of heating liquid in the apparatus to boiling and measuring the resistance of the sensor are repeated, most preferably whenever the apparatus is used to boil liquid. However in accordance with this feature the sensor is not recalibrated but rather its resistance value at boiling is compared with the original calibration. This process will show up any increase in the temperature of the sensor when liquid in the vessel is at boiling point. Such increases are usually brought about by the build-up of scale in the heater which means that the heater will generally tend to run hotter over time. Clearly it is immaterial whether the calibrated and measured resistances are compared or whether they are converted to corresponding temperatures.

Preferably a threshold is set for this discrepancy such that if the threshold is exceeded the user can be

alerted, e.g. with an audible or visual indication, to the scale build-up to allow the user to take remedial action, i.e. de-scale the apparatus. Additionally or alternatively the apparatus is preferably arranged to operate in a modified manner in the event that this threshold is exceeded. The control may simply not energise the heater. Preferably however it is arranged to reduce the power applied.

This is novel and advantageous in its own right and thus when viewed from a further aspect the invention provides a method of detecting scale build up in a liquid heating apparatus comprising measuring the temperature of the heater of the apparatus when liquid in the vessel is boiling, comparing said temperature to a reference temperature and reducing the power applied to said heater if said temperature is greater than the reference temperature by more than a predetermined threshold.

The invention also extends to a liquid heating apparatus comprising an electronic control arranged to operate the apparatus in this way and to said control means *per se*.

Thus it will be seen that in accordance with this aspect of the invention, power to the heater is reduced if scale build-up is detected. This is beneficial since it reduces the maximum temperatures achieved by the heater under these circumstances thereby avoiding failure of the heater due to overheating, and also reduces the temperatures experienced by the rest of the apparatus - e.g., control, seals, vessel wall etc. in preferred embodiments. Furthermore, by reducing the ordinary running temperature of the heater when scale build-up occurs, the nuisance operation of heater protection mechanisms such as a maximum temperature monitor, bimetallic actuator or a self-protecting feature on the heater itself, may be avoided.

The power to the heater may be reduced by any

available method. Preferably however it is reduced in accordance with the first aspect of the first invention disclosed herein. This is beneficial as it minimises the instantaneous temperatures experienced by the heater and so enhances the benefit achieved by reducing the power input when scale is detected.

A separate audible or visual indication is preferably given to the user that de-scaling is required, although this may not be necessary in view of the fact that the time taken to boil liquid in the apparatus will gradually increase and this may be sufficient indication that de-scaling should be performed.

The threshold is preferably less than 10°C, preferably between 5°C and 10°C.

The reduction in power may be a single step change but preferably it is reduced in smaller steps dependent upon, e.g. approximately proportional to, the amount by which the boiling temperature exceeds the threshold. The constant of proportionality is preferably therefore set so that power is cut off completely at a maximum discrepancy from the threshold.

As is alluded to above, the temperature sensed by the sensor may be somewhat greater than that of the liquid itself due to thermal lag arising from the thermal mass of the heater etc. Whilst this is of little consequence where the apparatus is only ever used to boil liquid since then the absolute value of the measured temperature has no effect, it will affect the accuracy of embodiments which will allow a user to specify a temperature below boiling to which to heat the liquid unless corrected for. It will also affect the accuracy of any display of current temperature. These will increase the error in calculated temperature beyond any systematic error resulting from the effect of a lower boiling point at higher altitudes discussed above.

In simple embodiments the temperature lag may be

assumed to be constant and thus simply applied as a negative offset to the temperature measured by the sensor. Whilst this is a reasonably valid assumption giving reasonably accurate results, the Applicant has realised that by reducing the power applied to the heater as the desired temperature is reached, the sensed temperature more accurately reflects the liquid temperature and it has been found that this can give more accurate results than by using a fixed offset.

This concept is novel and inventive in its own right - regardless of the method used to calibrate the sensor - and thus when viewed from a further aspect the present invention provides a method of heating a liquid to a predetermined temperature using a liquid heating apparatus having an electronic control means, comprising applying a first power to the heater of said apparatus, determining when the temperature of the liquid is close to the desired temperature and thereafter reducing the applied power to a second lower power until said desired temperature is reached.

The invention also extends to a liquid heating apparatus and an electronic control means arranged to operate the apparatus in this way, and to said control means *per se*.

As well as allowing a desired temperature to be more accurately achieved, this feature gives the perceived benefit of avoiding a sudden switching off of the heater. This is most marked for high power heaters which tend to generate a lot of noise whilst heating. In accordance with the invention however, heating will come to a gradual halt.

The reduction in power may be a single step change but preferably it is reduced in a series of smaller steps dependent upon, e.g. approximately proportional to, the distance to the desired temperature - in other words a feedback loop is used to control the power close to the desired temperature.

Preferably an offset is applied in determining when the liquid temperature is close to the desired temperature, with the directly measured temperature being monitored once the power has been reduced.

Where the type of heater is not specified in the foregoing description, a planar heater is preferably used, most preferably a thick film heater. Such a heater may, as has become common in thick film heaters used in hot water kettles and jugs, comprise a metallic substrate onto which is laid a glass ceramic insulating layer. Alternatively other types and constructions of thick film heater may be used.

The methods and liquid heating apparatus of the invention may be implemented using pure hardware means such as discrete components or hard-wired logic gates. Alternatively, the invention may be implemented at least partially using software, e.g. computer programs. It will thus be seen that when viewed from a further aspect, the present invention provides computer software specifically adapted to carry out the methods hereinabove described when installed on data processing means.

Furthermore it will be appreciated that the means specified in the apparatus of the invention may similarly comprise computer software specifically adapted to carry out the methods hereinabove described when installed on data processing means.

The invention also extends to a carrier comprising such software which when used to operate a control for an electric liquid heating apparatus comprising a digital microprocessor, causes, in conjunction with said microprocessor, said liquid heating apparatus to carry out the steps of the methods of the present invention. Such a carrier could be a physical storage medium such as a ROM chip, CD ROM or disk, or could be a signal such as an electronic signal over wires, an optical signal or a radio signal from a remote device. In a preferred

embodiment the carrier comprises an electronically erasable programmable read-only memory (EEPROM) - e.g. provided on a microprocessor.

It will further be appreciated that not all steps of the invention need be carried out by computer software and thus from a further broad aspect the present invention provides computer software such software installed on a carrier for carrying out at least one of the steps of the methods set out hereinabove. Similarly, not all of the means specified in the apparatus of the invention need comprise computer software and thus in the general preferred case, it is at least one of such means which comprises computer software.

Certain aspects of the invention will now be described using examples and embodiments thereof.

Example 1

This example takes the form of a computer simulation of an embodiment of an aspect of the invention, described by way of example only, with reference to the accompanying drawings which are output graphs of a simulation of a thick film heater, in which:

Figure 1 is a graph showing the input power profile of a known method of reducing the average power applied to the heater to 50% of its maximum;

Figure 2 is a graph showing the output power profile at the opposite side of the heater plate and the corresponding temperature profile for the input profile of Figure 1;

Figure 3 is a graph showing the input power profile for a method in accordance with the invention of reducing the applied power to 50%;

Figure 4 is a graph showing the output power and temperature profiles for the input in Figure 3;

Figure 5 is a graph similar to Figure 3 showing a

reduction in power to 10%; and

Figure 6 is a graph showing the output corresponding to Figure 5.

A computer model was set up to simulate the effect of the liquid contacting surface of applying various input power regimes to the heating track on the underside of the heater plate. For the purposes of the simulation the thick film heater was assumed to be a flat disk of stainless steel 100 mm in diameter, 0.5 mm thick having a mass 0.0322 kg and a specific heat capacity of 500 $Jkg^{-1}K^{-1}$.

The power density rating of the heating track was set at 60 Wcm^{-2}. The initial temperature of the plate and liquid was set to 100°C. The temperature of the liquid was assumed to remain constant for simplicity and temperature gradients across the thickness of the plate were ignored. The convective heat transfer coefficient of the liquid was assumed to be 2 $Wcm^{-1}K^{-1}$.

Initially a square wave series of one second pulses of power at 60 Wcm^{-2} was applied to the heater as shown in Figure 1 to simulate the method in which known liquid heating vessels operate. The gap between the pulses was also one second, thus giving a mark-space ratio of 50%. thus the R.M.S. or equivalent heating effect of this power regime is 30 Wcm^{-2}. Figure 2 shows the effect at the opposite i.e. liquid contacting surface of the plate. Plot A is the output power in Wcm^{-2} whilst plot B is the corresponding temperature in °C. As may clearly be seen the output power and temperature rise sharply during the first quarter of a second or so of each pulse having substantially reached an equilibrium within 0.5. seconds. It will be seen that the temperature reached and maintained is approximately 130°C and the full 60 Wcm^{-2} is dissipated for at least half the pulse.

Figure 3 shows an input power regime in accordance with the invention. As in Figure 1 this is a 50% mark-space ratio square wave pulse train with an amplitude of

60 Wcm^{-2} and thus an R.M.S. power of 30 Wcm^{-2}. However in this example the pulse length is just 0.02 seconds which corresponds to a single full mains cycle. As may be seen from Figure 4, the effect of this apparently simple modification is dramatic. The short duration of the pulses means that the output power (plot C in Wcm^{-2}) and temperature (plot D in °C) never reach their equilibrium values as they did in the previous case. Thus the maximum output power reached is approximately 35 Wcm^{-2} as compared to 60 Wcm^{-2} in the previous case. Similarly the maximum temperature reaches is only approximately 115°C compared to 130°C in the previous case. Thus although the average heating effect is the same in each case, i.e. 30 Wcm^{-2} R.M.S., in the latter case for example milk could be heated without burning whereas the 60 Wcm^{-2} it would experience in the former case would be sufficient to burn it.

Similarly the reduced maximum watts density significantly reduces the propensity for local boiling to occur at the surface of the heater during heating, and consequently the noise generated is correspondingly reduced. For example a reduction of power to 20% of maximum of 3kW, i.e a reduction of more than 6 dB has been found to reduce the sound emitted to an inaudible level even against the background of a quiet room

Figure 5 shows an input power regime similar to Figure 3 but this time with a 10% mark-space ratio, i.e. 6 Wcm^{-2} R.M.S. The effect is shown in Figure 6. It will be seen here that the maximum output power and temperature are even further reduced to approximately 12 Wcm^{-2} and 107°C respectively.

By contrast however if the power input of Figure 1 were modified to give the same R.M.S. power, i.e. by increasing the gaps to 9 seconds, the maximum power output and temperature would be unaffected since equilibrium is reached during the one second pulses.

It will be understood by those skilled in the art

that the examples described above may be modified in many respects within the scope of the invention and that they are provided for illustration only. In particular the simulations are necessarily idealised but are sufficiently realistic to demonstrate the characteristic features of the invention over the prior art.

The figure of 100°C was chosen for the initial plate temperature simply to ensure that the temperature could be plotted clearly on the same numerical scale as the power output. A more realistic value might have been say 80°C in which case the plate temperature would have exceeded 100°C in the case of the prior art method, thus causing local boiling, but not in the case of the method in accordance with the present invention.

Furthermore the actual values used for the examples may not be ideal for use in practice for other reasons - such as potential problems with requirements relating to the generation of electromagnetic interference and excessive influence on domestic electricity supplies. The skilled person may therefore need to modify the values used appropriately whilst retaining the concept of applying power sufficiently briefly so as not to establish equilibrium.

Example 2

A thick film electric heater is fabricated in accordance with known techniques and a positive temperature coefficient (PTC) thermistor is bonded to the heater plate so as to be in good thermal contact therewith. The whole assembly is allowed to cool to room temperature. A highly accurate resistance measuring device (which are well known *per se*) is used to measure the resistance R_1 of the thermistor whilst a thermocouple is used accurately to measure the temperature T_1 which it is experiencing. The heater and sensor assembly is then assembled into a jug and is sold

#to a consumer.

The control means in the jug is arranged to go into a calibration mode on its first operation. The user is instructed to fill the jug with water, switch it on and leave it to boil. The control means then applies power to the element until boiling is sensed by measuring the resistance of the thermistor. The rate at which the resistance changes is then used to determine when water in the vessel is boiling.

Once the water is boiling, the heater is deenergised. After a further two seconds to allow thermal equilibrium to be established, the resistance R_2 of the thermistor is measured by the control means. The temperature T_2 is assumed to be 100°C.

The temperature coefficient of resistance is then calculated as follows:

$$C_{TR} = (R_2 - R_1)/(T_2 - T_1)$$

The jug may now operate normally to display the temperature during heating and/or to heat to a desired temperature. The current temperature T_x is given by $T_x = C_{TR} \times (R_x - R_1) + T_1$, where R_x is the current thermistor resistance.

Whenever the jug is again set to boil water the temperature at boiling is measured and compared to T_2, i.e. 100°C. At first the temperature should be close to 100°C, but as scale builds up the temperature at boiling will rise. If the boiling temperature sensed by the thermistor exceeds 105°C, a warning message is given on a user display and a warning tone given to indicate to the user that the jug should be de-scaled. Furthermore the power applied to the heater is reduced from its maximum depending upon the amount by which the value of 105°C is exceeded. If the boiling temperature of the heater exceeds 200°C, power is reduced to zero.

It will be appreciated by those skilled in the art

that the above example is given for the purposes of illustration only and many variations are possible within the scope of the invention. For example both calibration steps could be carried out in the factory.

Furthermore for the purposes of simplicity a PTC thermistor having a linear temperature dependence was used in the example. If an NTC thermistor with an exponential temperature dependence is used instead, the algebraic manipulations would need to be amended accordingly.

Claims

1. A method of reducing the power output of a thick film heater to a predetermined fraction of its maximum power, said heater having a planar substrate which is electrically insulating on at least one face thereof and an electrically resistive heating track applied to said insulating face, said method comprising applying a series of regular periodic bursts of electrical energy to said heater wherein the bursts are sufficiently short that the face of the heater plate opposite the heating track does not reach an equilibrium temperature.

2. A method as claimed in claim 1, wherein the duration of said bursts is less than 500 mS, preferably less than 200 mS, more preferably less than 100 mS.

3. A method as claimed in claim 1 or 2 wherein the burst duration is a whole number of A.C. cycles.

4. A method of operating a thick film electric heater for a liquid heating apparatus comprising applying a reduced power to the heater in accordance with the method claimed in claim 1, 2 or 3; determining whether the rate of temperature rise of the heater is above or below a predetermined threshold value and increasing the power applied if the rate of temperature rise is below the threshold rate, but interrupting the supply of power to the heater if the detected rate of temperature rise is above the threshold rate.

5. A method of operating a thick film heater for a liquid heating apparatus comprising applying a reduced power to the heater; determining whether the rate of temperature rise of the heater is above or below a predetermined threshold value and increasing the power applied if the rate of temperature rise is below the

threshold rate, but interrupting the supply of power to the heater if the detected rate of temperature rise is above the threshold rate.

6. A method as claimed in claim 4 or 5, comprising measuring the time taken for the temperature to rise by a predetermined amount.

7. A method as claimed in claim 4, 5 or 6 comprising repeating said step of determining whether the rate of temperature rise is above or below a threshold value and increasing the power applied only if the threshold is not exceeded on both or all of said determinations, but interrupting said power if said threshold is exceeded on any of said determinations.

8. A method as claimed in any of claim 4 to 7 comprising making said determination continually.

9. A method of operating an electric liquid heating vessel comprising applying a reduced power to the heater of the vessel for a predetermined period, applying higher power thereafter and determining whether the rate of temperature rise of the heater is greater than a predetermined threshold value, and interrupting the power to the heater if the rate of temperature rise is above the threshold rate, but continuing to heat the liquid if it is below the threshold rate.

10. A method as claimed in any of claims 4 to 9 comprising increasing said power to maximum power.

11. A method as claimed in any of claims 4 to 10 comprising using said rate of temperature rise to determine the volume of liquid in said liquid heating vessel.

12. A method of estimating the volume of a liquid of known heat capacity being heated by an electric liquid heating apparatus, said method comprising applying power to the heater of said apparatus, measuring the increase in temperature of said liquid over a given time and calculating said volume on the basis of the time, heat capacity and amount of energy supplied to the heater during said time.

13. A method as claimed in claim 12 comprising measuring the temperature of said liquid via the heater.

14. A method as claimed in claim 11, 12 or 13 comprising reducing the power applied to the heater if the detected volume is above a predetermined level.

15. A method as claimed in any of claims 11 to 14 comprising reducing the power applied to the heater as liquid in the vessel approaches boiling.

16. A method of operating an electric liquid heating apparatus comprising detecting whether the volume of liquid in the apparatus is above a predetermined threshold, applying a first power to the liquid during a first heating phase in which the liquid is heated to an intermediate temperature and applying a second lower power during a second heating phase in which the liquid is brought to boiling.

17. A method as claimed in claim 16 comprising reducing the power of the heater using the method claimed in claim 1, 2 or 3.

18. A method as claimed in any of claims 4 to 17 comprising estimating the time taken for liquid in the vessel to reach a preset temperature.

19. A method of estimating the time required to heat liquid of known heat capacity received in a liquid heating apparatus to a predetermined temperature comprising estimating the volume of liquid in the apparatus, determining the amount of power to be applied to the heater of the apparatus and determining the time required on the basis of the heat capacity, volume and total energy to be applied.

20. A method as claimed in claim 18 or 19 comprising updating said estimate during heating.

21. A method as claimed in claim 18, 19 or 20 comprising using the time estimate to set a fixed time for which power is applied to the heater.

22. A method of operating an electric liquid heating apparatus to heat liquid received therein to a predetermined temperature comprising estimating the time which will be taken to heat the liquid to said temperature; defining a fixed heating time based on said estimate of time and applying power for said fixed heating time and thereafter interrupting or reducing the power to the heater.

23. A method as claimed in claim 22 wherein said predetermined temperature corresponds to boiling of the liquid in the vessel.

24. A method of heating a liquid comprising providing a liquid heating vessel with a thick film heater as claimed in claim 1, 2 or 3 and operating said heater at such a power that liquid in the vessel is heated substantially without generating any discernible noise.

25. A method as claimed in claim 24 comprising applying a predetermined power profile, the profile being

determined so as to maximise the power at a given point thereof whilst minimising the generation of noise.

26. A method of calibrating a thermal sensor arranged to measure the temperature of the substrate of a thick film heater for a liquid heating apparatus, said method comprising noting the resistance of the sensor at a first temperature, heating liquid in the apparatus to boiling, noting the resistance of said sensor and thereafter using said two resistances to calculate by interpolation or extrapolation the temperature of the sensor at temperatures below boiling.

27. A method as claimed in claim 26 wherein said first temperature is below the second.

28. A method as claimed in claim 26 or 27 comprising detecting boiling using the rate of change of temperatures of the sensor.

29. A liquid heating apparatus arranged itself to carry out the method of claim 26, 27 or 28.

30. A liquid heating apparatus comprising electronic control means including a temperature sensor which has been partially calibrated, said control means being arranged to heat liquid in the vessel to boiling, to measure the resistance of said sensor when the liquid is boiling and to calibrate the sensor on the basis of said measured resistance.

31. A liquid heating apparatus as claimed in claim 29 or 30 wherein a or the control means is arranged to carry out the calibration step the first time the apparatus is used by a consumer.

32. A method or apparatus as claimed in any of claims

26 to 31 wherein said sensor comprises a thermistor having a negative temperature coefficient of resistance.

33. A method as claimed in claim 26, 27 or 28 comprising repeating the step of measuring the resistance of said sensor at boiling and comparing the measurement with the original one in order to determine whether there is a discrepancy between the two which indicates that scale has built up on the heater.

34. A method as claimed in claim 33 comprising reducing the power applied to the heater if there is such a discrepancy.

35. A method of detecting scale build up in a liquid heating apparatus comprising measuring the temperature of the heater of the apparatus when liquid in the vessel is boiling, comparing said temperature to a reference temperature and reducing the power applied to said heater if said temperature is greater than the reference temperature by more than a predetermined threshold.

36. A method as claimed in claim 34 or 35 comprising reducing power to the heater in accordance with the method claimed in claim 1, 2 or 3.

37. A method as claimed in claim 34, 35 or 36 comprising giving a separate audible or visual indication to a user that de-scaling is required.

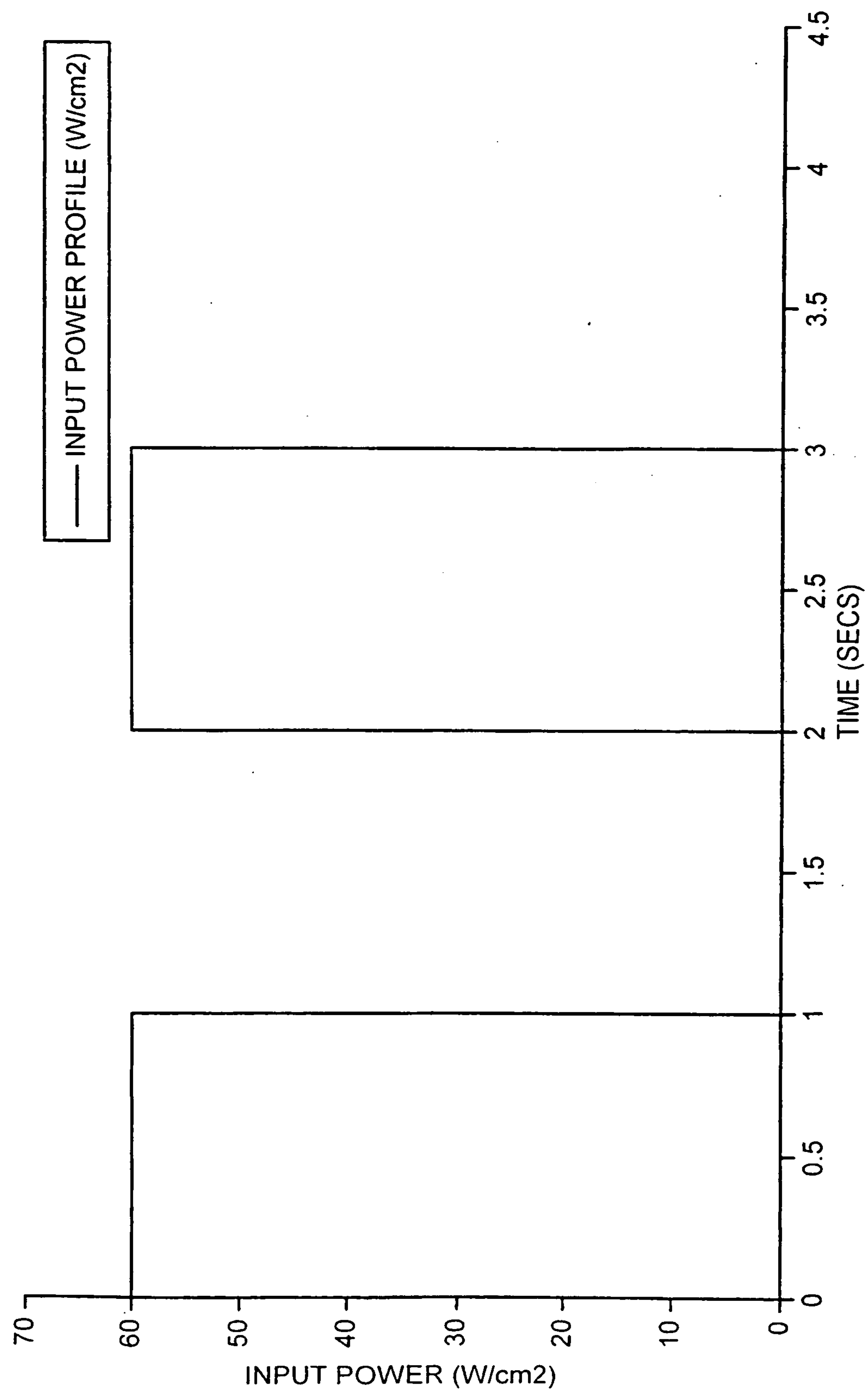
38. A method of heating a liquid to a predetermined temperature using a liquid heating apparatus having an electronic control means, comprising applying a first power to the heater of said apparatus, determining when the temperature of the liquid is close to the desired temperature and thereafter reducing the applied power to a second lower power until said desired temperature is

reached.

39. A liquid heating apparatus adapted to carry out a method as claimed in any of claims 21 to 28 or 32 to 38.

40. An electronic control for a liquid heating apparatus as claimed in claim 39.

41. Computer software specifically adapted to carry out a method as claimed in any of claims 21 to 28 or 32 to 38.


INPUT POWER PROFILE (W/cm2)
INPUT POWER (W/cm2)
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10
20
30
40
50
60
70
TIME (SECS)
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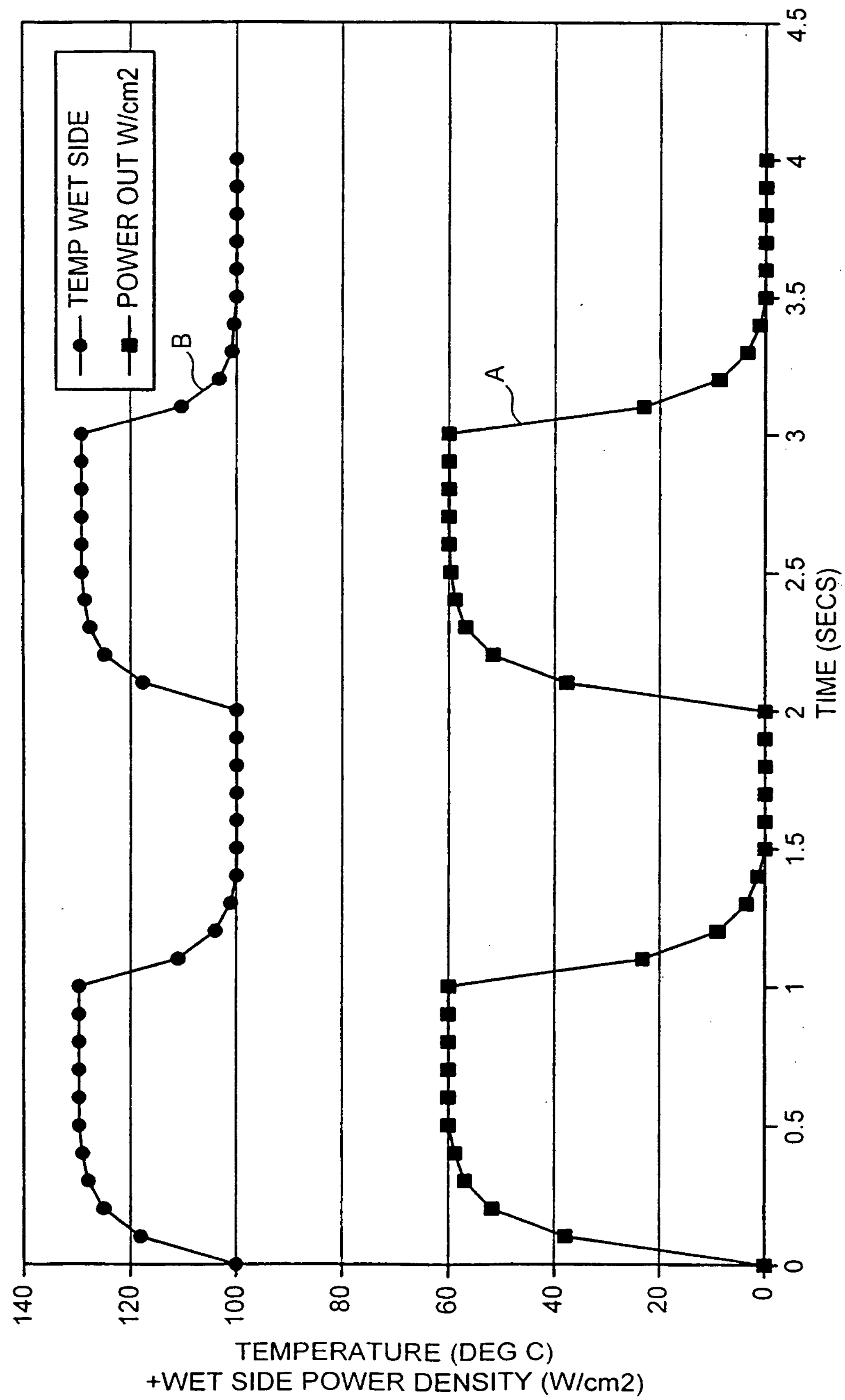
0.5
1
1.5
2
2.5
3
3.5
4
4.5

FIG. 1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POWER OUT W/cm2
A
B
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20
40
60
80
100
120
140
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+WET SIDE POWER DENSITY (W/cm2)
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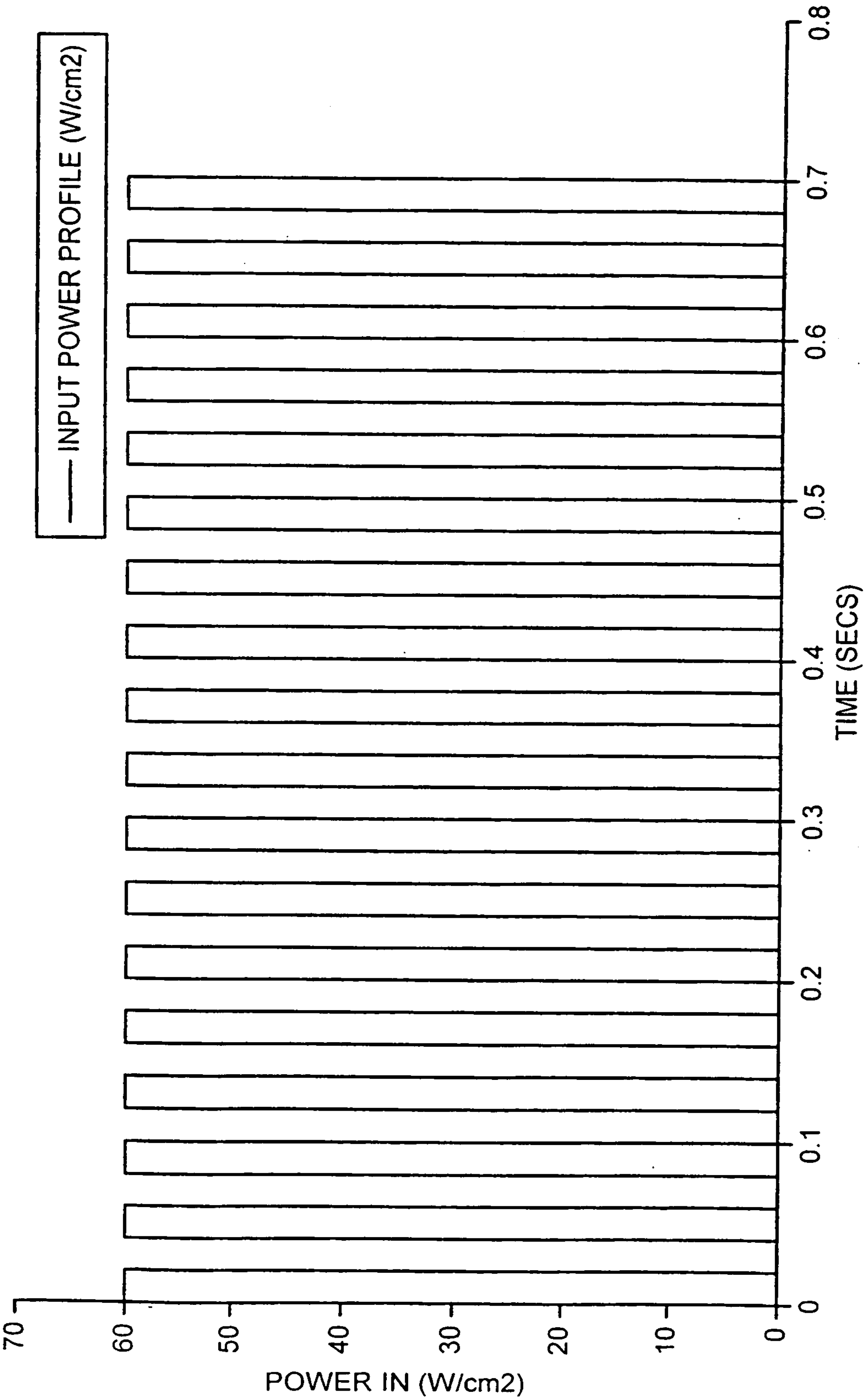
1
1.5
2
2.5
3
3.5
4
4.5
TIME (SECS)

FIG. 2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POWER IN (W/cm2)
TIME (SECS)
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10
20
30
40
50
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0.2
0.3
0.4
0.5
0.6
0.7
0.8

FIG. 3

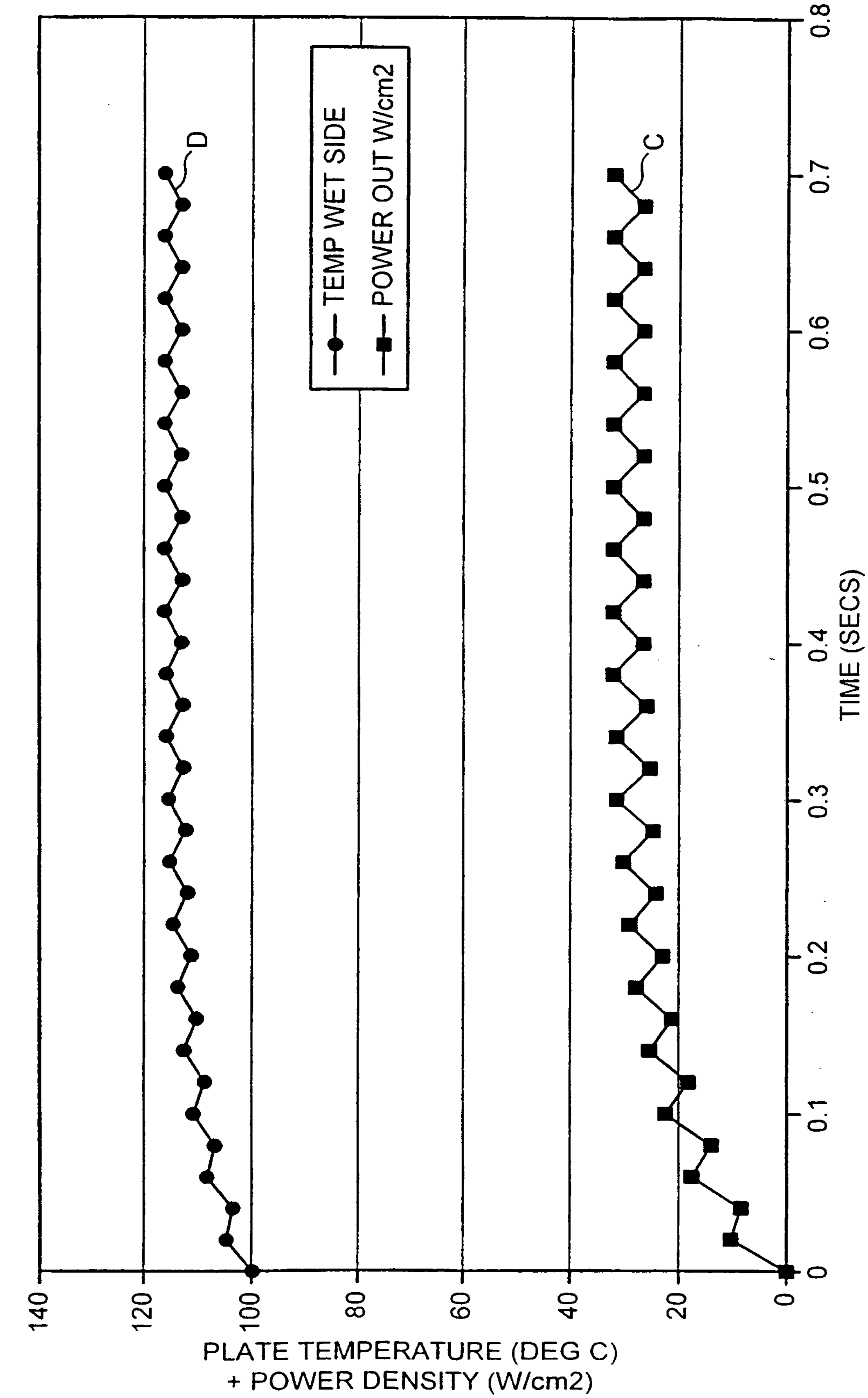
TEMP WET SIDE
POWER OUT W/cm2
D
C
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
TIME (SECS)
0
20
40
60
80
100
120
140
PLATE TEMPERATURE (DEG C)
+ POWER DENSITY (W/cm2)

FIG. 4

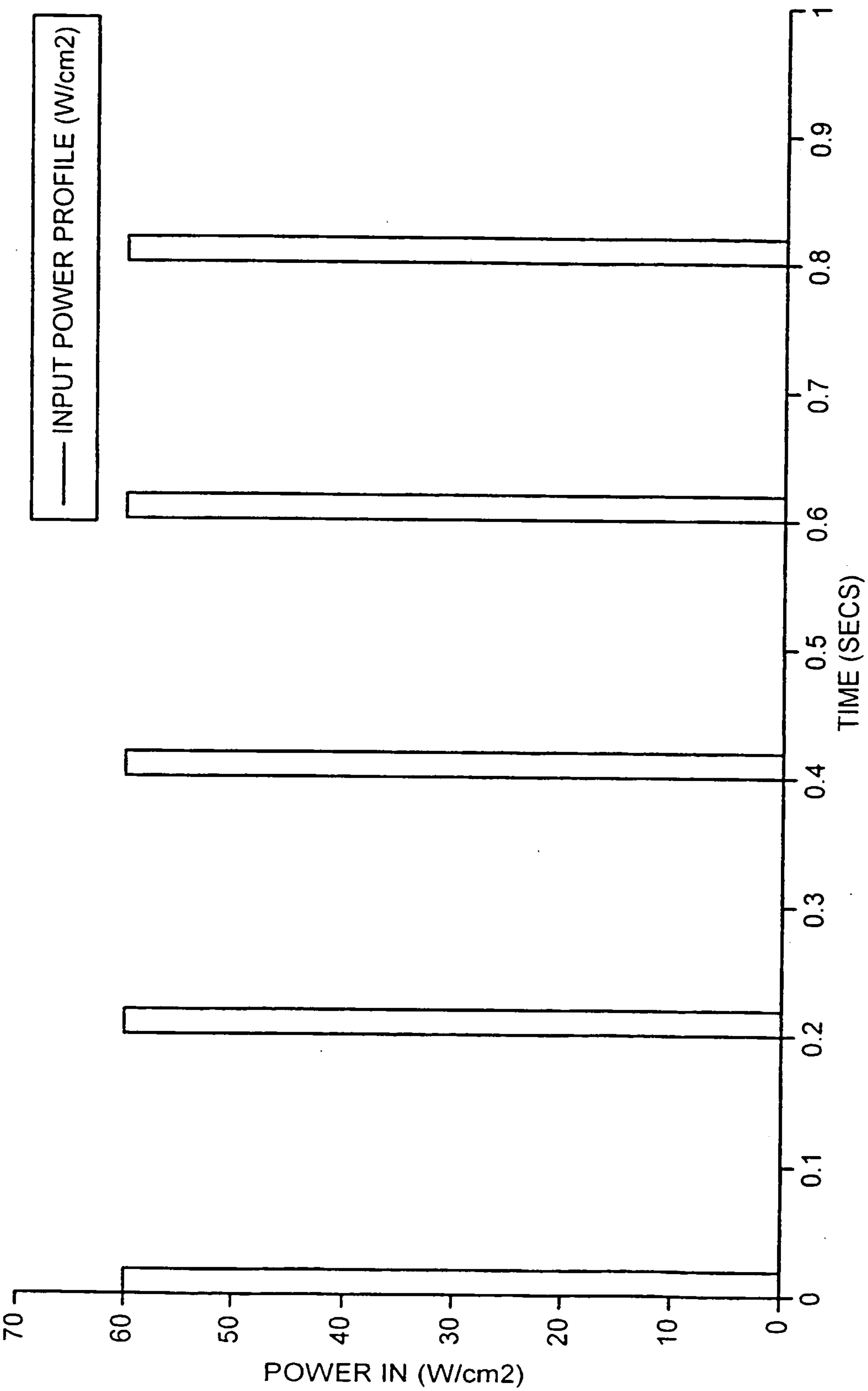
INPUT POWER PROFILE (W/cm2)
TIME (SECS)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
POWER IN (W/cm2)
70
60
50
40
30
20
10
0

FIG. 5

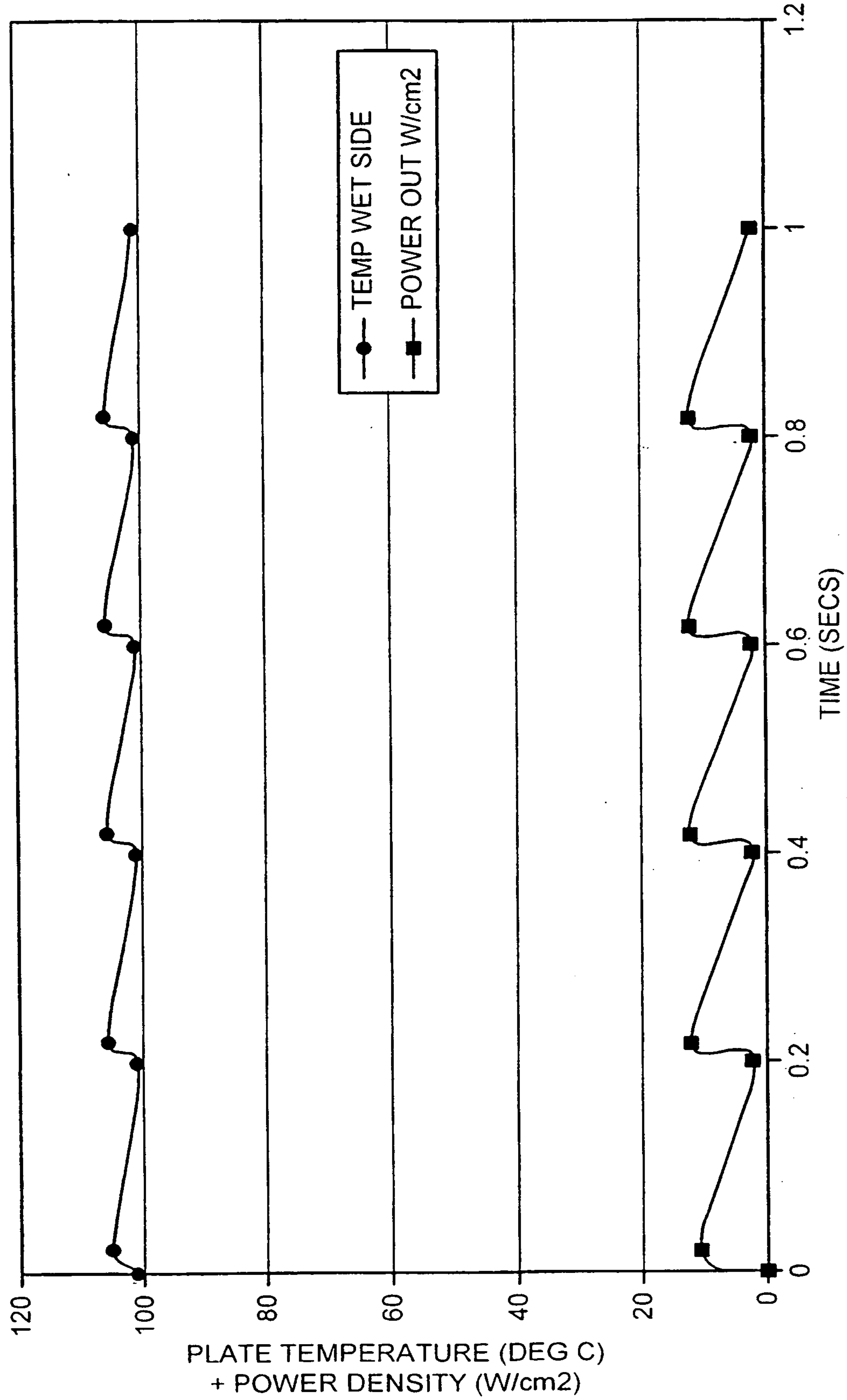
TEMP WET SIDE
POWER OUT W/cm2
TIME (SECS)
0
0.2
0.4
0.6
0.8
1
1.2
PLATE TEMPERATURE (DEG C)
+ POWER DENSITY (W/cm2)
0
20
40
60
80
100
120

FIG. 6

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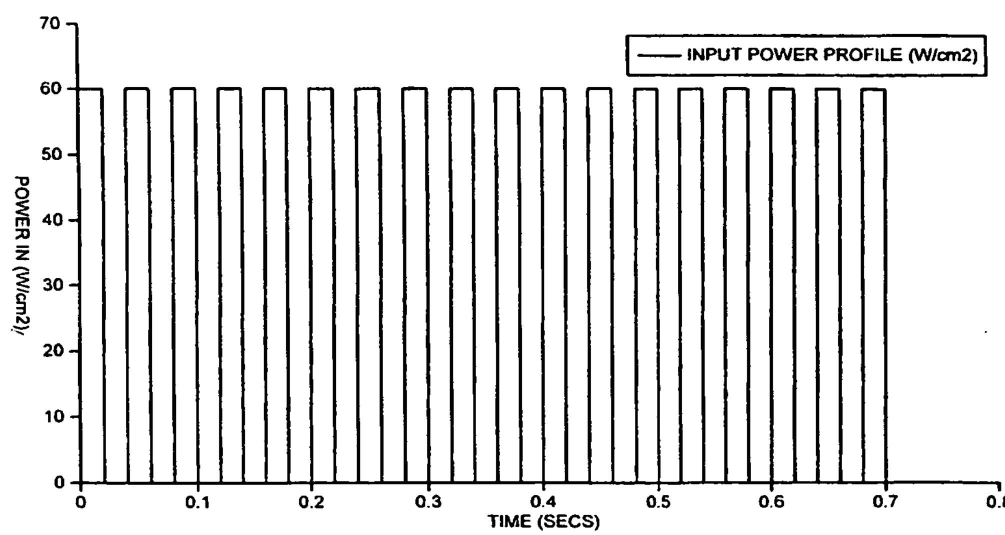
— *with international search report*

[Continued on next page]

(54) Title: ELECTRIC HEATER FOR LIQUIDS



(57) Abstract: A method of reducing the power output of a thick film heater to a predetermined fraction of its maximum power is disclosed. The method comprises applying a series of regular periodic bursts of electrical energy to the heater wherein the bursts are sufficiently short that the face of the heater plate opposite the heating track does not reach an equilibrium temperature. Also disclosed is a method of detecting dry switch-on by applying a lower power at the start of heating and determining whether a threshold rate of temperature rise is exceeded. In a method of calibrating a temperature sensor, the resistance at boiling and at another temperature (the latter e.g. being measured during manufacture) are measured and interpolation or extrapolation used. Other methods for estimating volume, reducing power as a given temperature is approached and detecting scale build-up are also disclosed.

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(88) Date of publication of the international search report: 20 December 2001

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 01/00379

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A47J27/21 A47J27/62

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 A47J H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97 04694 A (STRIX) 13 February 1997 (1997-02-13) cited in the application	1
Y	page 30, line 23 -page 31, line 20; figures 1,2,17 abstract	2-4
X	US 5 019 690 A (KNEPLER) 28 May 1991 (1991-05-28)	1
Y	column 6, line 14 -column 7, line 12; figure 13	2,3
Y	US 5 006 695 A (ELLIOTT) 9 April 1991 (1991-04-09) column 4, line 52 -column 5, line 24; figures 3,4	4

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 April 2001	17. 08. 2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Giesen, M

3

Interı nal Application No
PCT/GB 01/00379

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 99 02080 A (STRIX) 21 January 1999 (1999-01-21) page 21, line 37 -page 26, line 18; claims 7-15,23; figures 1-3 -----	1-4

3

INTERNATIONAL SEARCH REPORT	International application No. PCT/GB 01/00379

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 41
because they relate to subject matter not required to be searched by this Authority, namely:
Rule 39.1(vi) PCT - Program for computers

2. [ ] Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. [ ] As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. [X] No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-4, 24, 25

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-4, 24 ,25

A method of reducing the power output of a thick film heater to a predetermined fraction of its maximum power, said heater having a planar substrate which is electrically insulating on at least one face thereof and an electrically resistive heating track applied to said insulating face, said method comprising applying a series of regular periodic bursts of electrical energy to said heater wherein the bursts are sufficiently short that the face of the heater plate opposite the heating track does not reach an equilibrium temperature.

(Independent claim 1 with dependent claims 2 - 4, 24 and 25)

2. Claims: 5-11

A method of operating a thick film heater for a liquid heating apparatus comprising applying a reduced power to the heater; determining whether the rate of temperature rise of the heater is above or below a predetermined threshold value and increasing the power applied if the rate of temperature rise is below the threshold rate, but interrupting the supply of power to the heater if the detected rate of temperature rise is above the threshold rate.

(Independent method claims 5 and 9 with dependent claims 6 - 8, 10 and 11)

3. Claims: 12-23

A method of estimating the volume of a liquid of known heat capacity being heated by an electric liquid heating apparatus, said method comprising applying power to the heater of said apparatus, measuring the increase in temperature of said liquid over a given time and calculating said volume on the basis of the time, heat capacity and amount of energy supplied to the heater during said time.

(Independent claim 12 with dependent claims 13 - 15 and independent claim 16 with dependent claims 17 and 18)

&

A method of estimating the time required to heat liquid of known heat capacity received in a liquid heating apparatus to a predetermined temperature comprising estimating the volume of liquid in the apparatus, determining the amount of power to be applied to the heater of the apparatus and determining the time required on the basis of the heat

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

capacity, volume and total energy to be applied.

(Independent claim 29 with dependent claims 20 and 21 and independent claim 22 with dependent claim 23)

4. Claims: 26-34

A method of calibrating a thermal sensor arranged to measure the temperature of the substrate of a thick film heater for a liquid heating apparatus, said method comprising noting the resistance of the sensor at a first temperature, heating the liquid in the apparatus to boiling, noting the resistance of said sensor and thereafter using said two resistances to calculate by interpolation or extrapolation the temperature of the sensor at temperatures below boiling.

(Independent method claim 26 and independent device claim 30 with dependent claims 27 - 29 and 31 -33)

5. Claims: 35-37

A method of detecting scale build up in a liquid heating apparatus comprising measuring the temperature of the heater of the apparatus when liquid in the vessel is boiling, comparing said temperature to a reference temperature and reducing the power applied to said heater if said temperature is greater than the reference temperature by more than a predetermined threshold.

(Independent claim 35 with dependent claims 36 and 37)

6. Claims: 38-40

A method of heating a liquid to a predetermined temperature using a liquid heating apparatus having an electronic control means, comprising applying a first power to the heater of said apparatus, determining when the temperature of the liquid is close to the desired temperature and thereafter reducing the applied power to a second lower power until said desired temperature is reached.

(Independent method claim 38 with dependent claim 39 and independent device claim 40)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 01/00379

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WO 9704694 A	13-02-1997	CN 1185725 A	24-06-1998
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